6. *Percentage of run-off.*—(*a*) It is fortunate for agriculture in Iowa that the percentage of run-off from storm rainfall is small. In the August, 1929, flood, the percentage of the precipitation reaching the stream, amounted to only 18.3 per cent at Iowa City and 33.7 per cent at Marshalltown. Experiments indicate that very little, if any, of the midsummer precipitation percolates deep enough into the soil to replenish the ground water and replenish the supply available for subsequent run-off. Hence, the balance of the water was either evaporated immediately or stored in the upper layers of the soil for future evaporation and plant use. The graph showing the comparison of the cumulative run-off and precipitation is shown in Figure 4.

(*b*) In the following table, the percentage storm rainfall appearing as flood run-off is listed for other midsummer floods on Iowa streams. On the larger basins, the flood run-off rarely exceeds 30 per cent of the precipitation, although occasionally on some smaller watersheds almost 70 per cent of the storm rainfall has reached the streams.

TABLE 1.—*Percentage run-off of typical Iowa summer floods*

River	Gaging station	Drainage area, square miles	Date	Total precipitation, inches	Total run-off, inches	Per cent run-off of precipitation
Iowa	Iowa City	3, 230	May-June, 1903	7. 10	1. 58	22. 3
			May-June, 1918	6. 99	2. 36	33. 8
			June-July, 1924	4. 72	. 84	17. 8
			August, 1929	4. 48	. 82	18. 3
Do	Marshalltown	1, 500	do	3. 07	1. 05	34. 2
Cedar	Cedar Rapids	6, 570	May-June, 1903	5. 75	1. 09	19. 0
Des Moines	Kalo	4, 290	May-June, 1915	5. 34	1. 56	29. 2
			July, 1920	4. 53	1. 36	3. 00
Do	Keosauqua	14, 090	May-June, 1903	8. 53	2. 59	30. 4
			June, 1905	1. 92	. 49	25. 6
			May-June, 1917	5. 86	1. 79	30. 5
Raccoon	Van Meter	3, 450	May-June, 1915	6. 46	1. 81	28. 0
			May-June, 1917	5. 95	1. 88	31. 6
			September, 1926	4. 62	1. 79	38. 8
Skunk	Coppock	2, 915	May-June, 1917	7. 16	2. 89	40. 0
			May-June, 1918	7. 16	2. 00	28. 0
			June-July, 1924	3. 78	1. 36	36. 0
			September-October, 1926.	12. 56	4. 58	36. 4
Do	Augusta	4, 285	May-June, 1917	6. 91	2. 90	42. 0
			May-June, 1918	6. 10	1. 64	26. 9
			June-July, 1924	4. 38	1. 80	41. 1
			September-October, 1926.	12. 85	5. 40	42. 0
Do	Ames	315	June-July, 1924	2. 54	1. 40	55. 1
Squaw Creek	do	205	do	2. 29	1. 54	67. 3
			September-October, 1926.	12. 85	3. 35	26. 1
Ralston Creek	Iowa City	3. 0	June, 1926	2. 65	. 49	18. 5
			September, 1926	1. 98	. 78	39. 4
			do	1. 84	. 82	44. 5
			May, 1927	1. 04	. 32	30. 7
			do	1. 23	. 59	48. 0
			do	. 59	. 41	69. 5
			June, 1927	4. 88	. 05	62. 4
			June, 1928	2. 06	. 52	25. 0
			July, 1928	1. 35	. 19	13. 8
			do	1. 07	. 45	41. 7
			August, 1928	1. 61	. 61	37. 9
			do	3. 30	. 90	27. 0
			June, 1929	1. 77	. 34	25. 4
			June-July, 1929	2. 54	. 71	27. 9
			August, 1929	2. 76	. 76	27. 5
			June, 1930	4. 17	1. 52	36. 3
			do	1. 11	. 19	17. 2
			September, 1930	5. 07	1. 28	25. 2

THE TECHNICAL USE THAT ENGINEERS MAKE OF UNITED STATES WEATHER BUREAU OBSERVATIONS

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The work of the civil engineer embraces the planning, construction, and operation of both private and public enterprises and improvements. In connection with these activities he probably makes use of a greater variety of meteorological data than any other class of citizens, and in so doing affects the welfare of many people. It should therefore be of interest to meteorologists to know of some of the technical uses that engineers make of United States Weather Bureau observations. These are outlined in this paper together with suggestions as to ways in which the value of the observations could be increased.

PRECIPITATION

Precipitation is one of the most important classes of meteorological data which the engineer, and especially the hydraulic engineer, uses. It is fundamental to the planning of many projects and is very important in the design of hydraulic structures. It is necessary to know not alone the quantity of precipitation during long periods of time such as months, years, and groups of years, but also the rate or intensity for short periods of minutes and hours. The character of the precipitation, whether rain or snow, is also important.

Quantity.—Knowledge regarding the quantity of precipitation or depth in inches falling during periods of 24 hours or more, is of greatest importance in making water supply estimates for new hydraulic projects and for enlargement of existing systems. The proposed use of water may be for one of a great variety of purposes, such as domestic, industrial, municipal, irrigation, hydroelectric power, navigation, mining, or recreation. In every instance, however, it is necessary to know definitely whether sufficient water is available for the proposed use, both in the dryest season of the year and also during the dryest year which may be expected to occur. Streamflow measurements are of course depended upon to the extent available, but must usually be supplemented by studies of precipitation. The character of records required for this purpose range from long term average monthly and annual precipitation extending over periods of 50 or more years, to the actual precipitation which occurred on a specific day or during a certain storm. The data published in the monthly issues of Climatological Data are as much sought after in this connection as are the annual summaries or the occasional long-term summaries issued by the bureau.

In regions where there is a definite winter rainy season, such as on the Pacific coast of the United States, the compilation of precipitation data on the basis of the season instead of the calendar year is of great benefit to engineers, for it permits of immediate use of the data in water supply studies without the necessity of laborous preliminary computations. Precipitation records have been published by the Weather Bureau in this form in recent years, at least for the California section, using the period July 1 to June 30, and have been a source of great satisfaction to engineers. Seasonal compilations show clearly the character of the rainy season, whether wet or dry, and permit of the direct comparison of stream flow with the precipitation which produces it.

There is great variety in the application which is made of quantitative precipitation data in water-supply studies. The principal use is in supplementing stream-flow records. By their use it is possible to estimate the normal or flood flow of surface streams supplied by run-off from precipitation occurring during periods or at points for which stream-flow observations are not available. These studies enable the engineer to determine whether storage is necessary to produce the required water supply, and if so, the reservoir capacity which will be necessary. In recent years more and more attention has been given to ground water as a source of supply. As precipitation is an important source of ground water, this has led to the investigation of the absorption from precipitation by the soil and other natural formations. This involves the study of precipitation from each individual storm in connection with soil moisture and evaporation. Studies of this nature enable the engineer to determine the extent and reliability of the flow from springs and the amount of ground water which is permanently recoverable by pumping from wells. Precipitation, in addition to being the source of stream flow or ground water used in irrigation, is frequently a direct source of soil moisture for growing agricultural plants. The ascertainment of what proportion of the annual plant requirements will be thus obtained directly, is of great importance in certain localities in determining the supply to be provided for irrigation works.

Another use of precipitation data is in forecasting the current season's supply as an aid to operation of existing water systems. This is of particular value where precipitation occurs as snow at high elevation and the melting period carries over into the summer. Elaborate snow surveys are now made during the winter and spring months of each year by various State, Federal, and private agencies throughout the West. In compiling the results of such surveys, extensive use is made of Weather Bureau precipitation data in comparing the observations with normal and in preparing the forecast for areas of early snow melting. The results of the surveys are widely sought by municipalities, water districts, and water and power companies, as the basis for making water contracts and planning each year's operations.

An entirely different use of quantitative precipitation data is that in connection with the design of land-drainage projects. In this case it is desired to determine the quantity of water absorbed by the soil from precipitation and which is to be removed by drainage works. This information is essential in determining the sizes of drain pipe and drainage outlets, the capacity of drainage pumps, etc. Daily and storm records are sought for this purpose as well as the amount of precipitation during longer periods.

Isohyetose maps.—It is frequently necessary in making water-supply studies to prepare isohyetose maps, or maps showing lines of equal depth of precipitation, either for a single storm, a whole season, or as an annual average during a long period. For general study such a map might cover some large geographical or political unit, but for specific studies it would be confined to a single watershed or group of adjacent watersheds. A proper geographic distribution of precipitation stations is of great importance in the preparation of such a map, since topography and slope is a primary factor in local precipitation. If the watershed is one of low relief and well settled, there may be but little local variation and existing stations may be adequate. If, however, part or all of the watershed is mountainous and sparsely settled, the existing stations will probably be inadequate for the purpose. There are frequent instances in the mountainous portions of the West where differences in average annual precipitation of 500 to 1,000 per cent occur within distances of from 10 to 40 miles. A careful local study of the relations of precipitation and elevation on windward and leeward slopes of mountain ranges may sometimes help to supplement a deficiency of mountain stations, but on the Pacific slope there are many very important watersheds which have too few stations within or even near them to make feasible the construction of isohyetose maps. The value of these maps is so great in a State such as California, where every drop of water is being inventoried and plans and cost estimates prepared for its ultimate use, that a very definite effort would be justified to overcome this deficiency. It would not necessarily involve a great increase in the total number of precipitation stations, but certainly a redistribution of stations with respect to critical topographic position would be required. Such a program might well include regular and cooperative stations maintained by the Weather Bureau as well as those maintained by private or municipal agencies.

Intensity of precipitation.—Increasing density of population and the development of the automobile have created a great popular demand for paved streets and highways, which in turn have given rise to the necessity of providing storm drainage. The latter may be accomplished by the construction of a simple culvert under a surfaced thoroughfare, or may involve the construction of an extensive system of storm sewers, or even the intricate combination of flood control reservoirs and artificial channels costing millions of dollars, such as being built for protection of the thickly populated areas of Los Angeles County, Calif. Regardless of the magnitude of the improvement, the determination of the quantity of water to be carried, and hence the required size of the pipe, conduit, open channel, or capacity of flood control reservoir, can best be determined from records of maximum rainfall intensity, that is, the greatest quantity falling during periods of five minutes and more up to several hours but usually less than 24 hours. By study of the flood run-off characteristics of the tributary drainage area, together with actual correlation of time of occurrence and intensities of heavy rainfalls and resulting flood flows at any point, it is possible to establish definite relations between rainfall and flood run-off intensities.

Such data can only be obtained by installation of an automatic rainfall recorder and careful study of the record sheets. In order to be of greatest usefulness such a record should include the storm of maximum intensity to be anticipated in the region, and hence the longer the period covered, the more valuable is the record. For large storm drainage systems it is necessary to have several such records, especially where a portion of the drainage area is mountainous. The U. S. Weather Bureau obtains such data at important population centers and much use is made of them as a basis for storm sewer and culvert design. The originals [W. B. Form 1017–Met'l] of such records are sent to Washington, D. C., for filing, and it would often be of convenience to engineers if photostat negatives of these records were kept in the office of origin. In the more thinly populated areas there is very little data available, and for design of highway and railway culverts, flood control reservoirs, reservoir spillways, etc., it is still necessary to use assumptions in the design of waterway areas.

Character of precipitation.—In making water-supply estimates it is very important to have knowledge of the character of precipitation, whether rain or snow, and if the latter, the equivalent depth of water. Snow falling at high altitudes melts slowly and is the equivalent of reservoir storage in maintaining summer streamflow. It is very essential, however, to know the equivalent depth of water of the snow catch or the water content of snow on the ground. In the published records of precipitation falling as snow the catch is reduced to equivalent water, but there is no information regarding the water content of snow on the ground. This would be a very useful addition to the extensive snowfall records regularly published by the Weather Bureau.

TEMPERATURE

The meteorological data next to precipitation in importance to the engineer is probably air temperature. He is interested both in average values and in extremes, especially where minimum values go below freezing. Daily, monthly, annual, and 10-year annual averages, as published by the Weather Bureau, are all in demand. One of the important uses of such data is in the planning and financing of irrigation systems. Temperature controls the length of the irrigation season, the character and variety of crops which can be successfully grown, and the number of crops which can be raised each year. Knowledge of these is essential for adequate preliminary investigation of irrigation projects and the financial success of such projects frequently depends upon the availability of complete temperature data.

The design of engineering structures and plant is frequently influenced by temperature conditions. Provision for ice control in reservoirs and canals is necessary in a region where freezing temperatures prevail. Highway subgrades must also be protected from frost heave by adequate drainage, and concrete structures which withstand water pressure must be made of sufficient thickness and density to prevent spalling off of the face by the freezing of water in the interstices of the material. Provision for artificial heating in buildings and temperature control in steam power plants is also dependent upon knowledge of air temperature.

Large outdoor construction operations are vitally influenced by temperature. Quarters for men engaged upon the work must be provided which will mitigate as far as possible the extremes of heat and cold. Transportation must be planned which will not be disrupted by cold weather. Provision for hot water as a feature of concrete mixing plant must be made if air temperature falls below freezing for any length of time, and also protection at night for each day's fresh pour. Temperature conditions are also of importance in selecting locations for construction plants and camps as well as the more permanent locations for industrial plants or communities. As an example of the latter, the choice of location for Boulder City, made by the engineers of the United States Reclamation Service, was largely based on temperature conditions.

Temperature is the most important factor controlling evaporation during an extended period of time, such as a month or a year. Air temperature is frequently studied by hydraulic engineers in the absence of direct observations to determine the approximate evaporation from proposed reservoir surfaces.

WIND

Information regarding wind movement is probably as much sought after by engineers as temperature. Direction, velocity, and pressure against high buildings are all desired. Wind direction has an important bearing on the layout of buildings and grounds, and especially upon plant location where offensive odors, smoke, dust, or fumes are produced. Sewage treatment, garbage treatment, and various industrial plants such as smelters, cement plants, etc., must all be carefully located with respect to prevailing winds so as not to create nuisance in established communities. Floating solids on lakes and reservoirs and dust and flies in the air are all carried by the wind.

Knowledge of wind velocity is often of importance in planning construction operations. For example, work on bodies of inland water which requires floating equipment, may encounter considerable interruption by reason of seasonal or periodic daily winds of velocity great enough to produce waves. Wind velocity is also of importance in studying short time variations in evaporation rate from reservoirs and the fluctuations in level of lakes. The greatest use which engineers make of wind velocity data is in connection with building design. Among the other forces which may act upon isolated buildings are those induced by wind. Partial failures of large modern buildings have occurred during heavy winds, as at Miami, Fla., during the hurricane of several years ago, and for buildings of lighter construction it is necessary to provide against wind forces of much lesser degree. Wind velocities are observed at all regular Wheather Bureau stations and published as average hourly wind movement for each month. These are of little value to the designing engineer, however, since wind movement is very irregular, and it is maximum velocities which do the damage. The printed recording anemometer sheets are of much greater value. These must be consulted for considerable periods of time in order to determine the relative probability of maximum winds of various intensities. If photostat negatives of these records were kept in local Weather Bureau offices it would increase the usefulness of such data.

There is great difference in wind velocity at differing heights above the surface of the ground. There is no standard height for Weather Bureau anemometers and no information published relative to surroundings or height at any station. It thus is necessary to study at first hand the environment of equipment at wind velocity stations in order to properly use the records. It would be of considerable value to have such information in published form, illurtrated by sketches or photographs. The exposure on the tops of tall buildings, which is quite common, is not always productive of a true wind record, and it is to be hoped that it may sometime become possible to place anemometers on skeleton towers such as radio towers, where they will be free from eddies and cross currents. Such a location would also be ideal for determining the effect of differing elevation upon wind velocity.

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The conversion of wind velocities into wind pressures is a step which, although possibly not a meteorological problem, is yet of greatest importance to the engineer and one about which very little is known. The erection of large and costly structures in areas of high wind velocity is now causing concern to the designing engineer, and there is great need of scientific investigation of this subject. Such pressures vary greatly, not only with wind velocity but with shape and area of the exposed surface.

EVAPORATION

This is a meteorological process of greatest interest to the engineer as it represents an important loss of water after the latter has been reduced to possession in a reservoir or canal system. All water supply estimates must take it into consideration, and it frequently influences the operation program of water systems. Evaporation rates from free water surfaces differ greatly depending upon the temperature, humidity, and movement of the air, the temperature of the water, and the area of the water surface. The engineer usually desires to know the daily, monthly, and annual rate from a large water surface such as a lake or reservoir. It has been found by experiment that the evaporation from small pans set on or even in the ground, does not reproduce conditions on the surface of a large water body. The nearest approach to reproduction of actual conditions with a small pan is when submerged and floating upon the surface of a large body of water, with water level at the same elevation both inside and outside the pan, and side walls of the pan not projecting far above the water level. Such a pan 3 feet square or circular, protected more or less from wave splash, is frequently installed by engineers. For a land pan set into the soil it has been found that the diameter must be at least 12 feet before conditions closely approach those of a large water surface.

The standard Weather Bureau pan is 4 feet in diameter and set on a platform slightly above the ground surface with free air circulation beneath. Observations from such a pan have been of little value to engineers until very recently when intensive investigations were made with pans of different sizes, shapes, and exposures, to develop the general principles involved. Most of this experimental work has been done by the Division of of Agricultural Engineering, United States Department of Agriculture, in the vicinity of Denver, Colo., although it is understood that similar work is in progress in California. The data thus far available indicate that a factor of 0.70 applied to the evaporation as observed in standard Weather Bureau pans, will indicate approximately the loss from a large water surface exposed to similar atmospheric conditions. This factor, although possibly subject to modification under conditions differing from those at Denver, as for example, relative day and night temperatures, now enables the engineer to utilize Weather Bureau evaporation data. Recent studies made by the writer in the San Francisco Bay region, where there have been six records kept at various times with widely differing pan equipment and exposure and including one Weather Bureau pan, showed that all observations could be reduced to reasonable agreement when corrected for differences of temperatures and pans.

OTHER DATA

The four classes of observational data made available by the Weather Bureau, as discussed above, are the principal ones used by engineers. There is frequent use of other data, such as relative humidity, barometric pressure, sunlight hours, killing frosts, and especially the current weather forecasts. The latter are of frequent use in planning field work, construction operations, transportation of material, and the operation of reservoirs and canals. Most hydraulic engineers make it a daily practice to examine the weather map and speculate as to the probability of rain or snow within the next day or two. The long continued series of dry years through which we have been passing may have had its influence in forming this habit, although the use of reports from vessels on the Pacific Ocean in making forecasts has greatly stimulated it.

All governmental bureaus must of necessity carry on their work under definite financial appropriations or budget allowances, and in accordance with fiscal and departmental rules and regulations. These are restrictions which more or less limit any organization, whether governmental or private, but must be especially rigid in the governmental service. The United States Weather Bureau, being one of the older scientific bureaus of our Government, is possibly more burdened with these restrictions than some of the more recently organized services. Regardless of such handicap, however, the work of the Weather Bureau is touching an ever-increasing number of people and serving a widening variety of interests.

The usual purpose for the creation of permanent governmental agencies engaged in scientific work is to meet some direct need either of the people or of government acting in the interest of the people. Once organized, with an established administrative routine, the original purpose is sometimes lost sight of either by a failure to keep pace with the changing needs of the people for current information of a scientific character, by a lack of vision and energy in undertaking fundamental research, or by inadequate facilities for making the data available. Although this tendency has at times been noticeable in governmental bureaus of the United States, it has never reached such extremes as have been witnessed in certain older countries where the ideal of government being for the benefit of the people is not so generally recognized.

In the practice of his profession the writer has had contact with the meteorological departments of foreign governments as well as the United States, and has been impressed by the differences in objective. Our Weather Bureau is not administered as a background for the scientific interests of any official or organization, nor to meet the specific requirements of some other branch of the Government service to the exclusion of the needs of the public. Its objective is to render promptly a wide variety of service to the extent which funds and departmental rules and regulations will permit, and in so doing it is filling a real need. Many engineers would like to see broader scope or refinement in certain phases of its meteorological work, but it should be remembered that in the final analysis the burden of improvement and enlargement can not be carried by bureau officials alone. It must be participated in by public spirited citizens working through the various channels which create and make effective public opinion.